Hybrid prism-grating stretcher

Ivan Yakovlev

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Ultra Intense Laser Technology and Intense Field Physics

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Federal Research Center The Institute of Applied Physics
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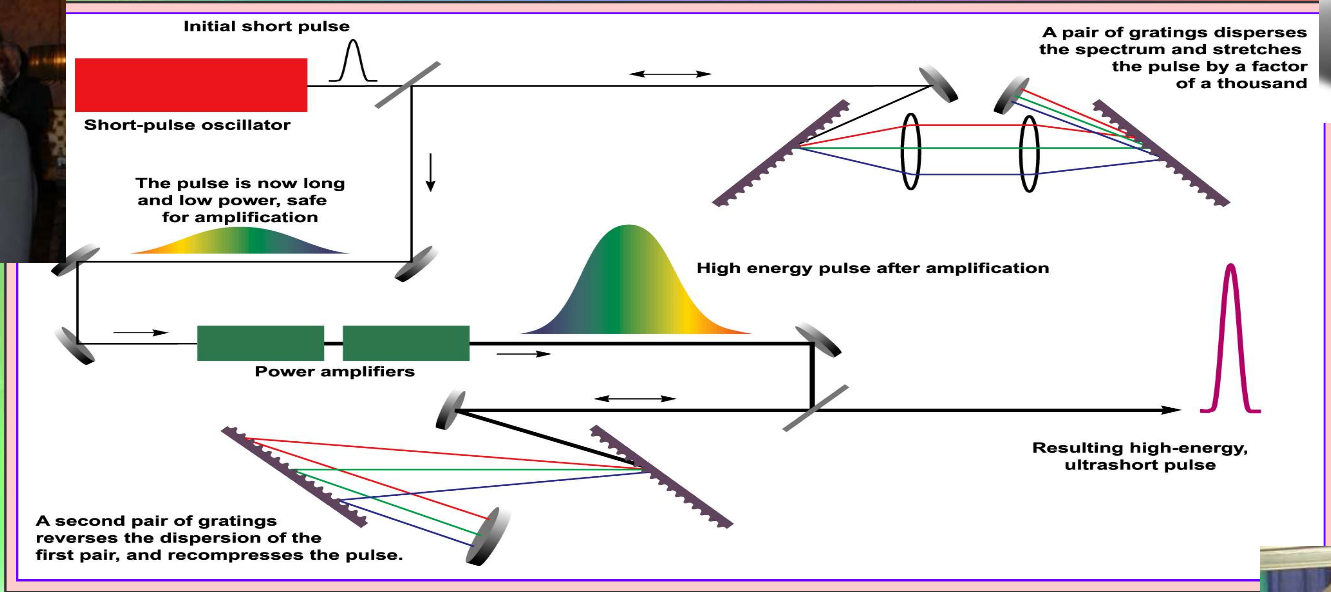
Chirped-pulse amplification - CPA

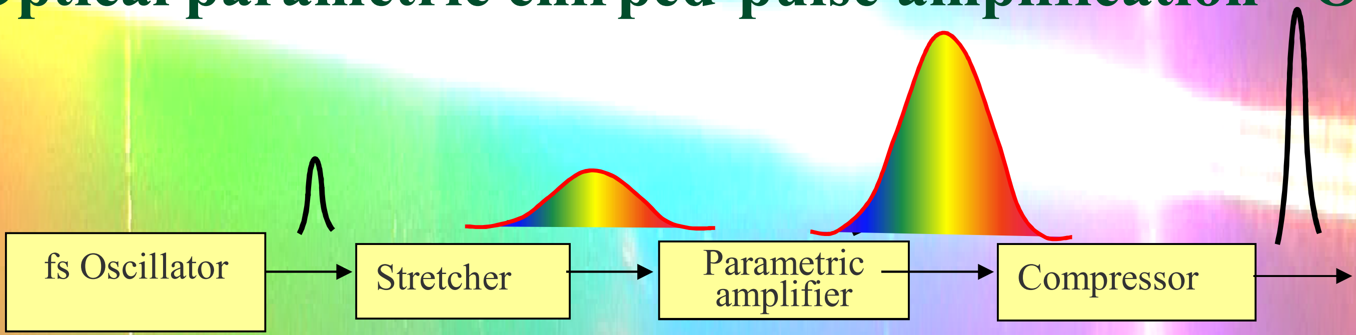
Donna Strickland
and
Gerard Mourou

1985



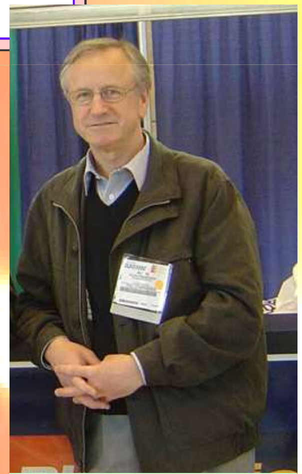
2018

Optical parametric chirped-pulse amplification - OPCPA



τ_0 | $T=K\tau_0$, $\Delta\Phi_{str}$ | T, $\Delta\Phi_{amp}$ | $\tau_{out}=\tau_0$, $\Delta\Phi_{com}$

1986



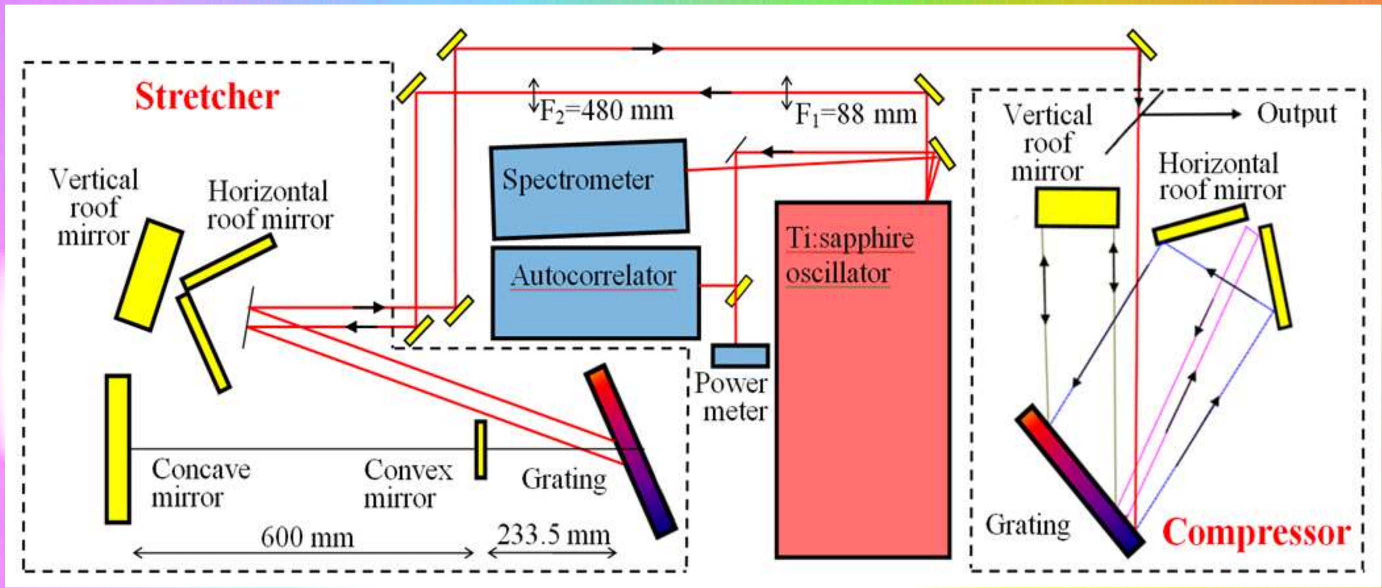
Algis Piskarskas
(Vilnuis
University,
Lithuania)

Phase matching condition of stretcher, amplifier and compressor:

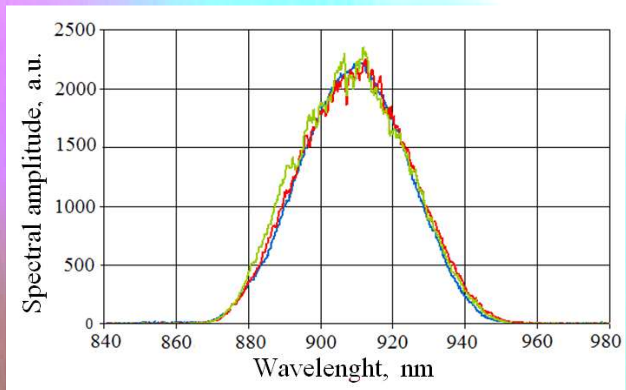
$$\Delta\Phi_{str}(\omega_1)+\Delta\Phi_{amp}(\omega_1)+\Delta\Phi_{com}(\omega_1)=0$$

$$\Delta\Phi_{str}^{(i)}(\omega_1)=-\Delta\Phi_{com}^{(i)}(\omega_1),\ i=2,3,\ldots$$

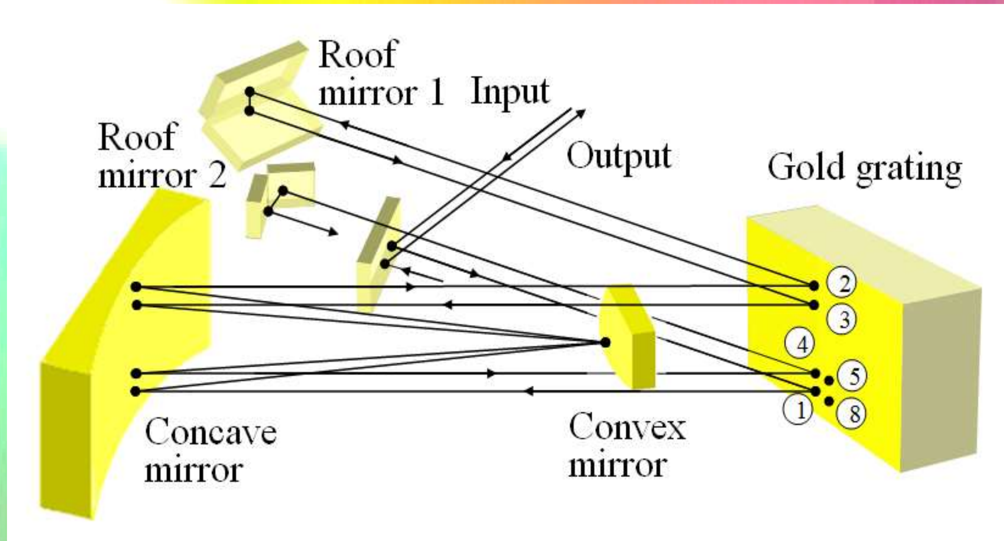
Offner triplet telescope stretcher for the PEARL laser facility



Ti:sapphire femtosecond master-oscillator with a central wavelength of 910 nm needed a new stretcher…



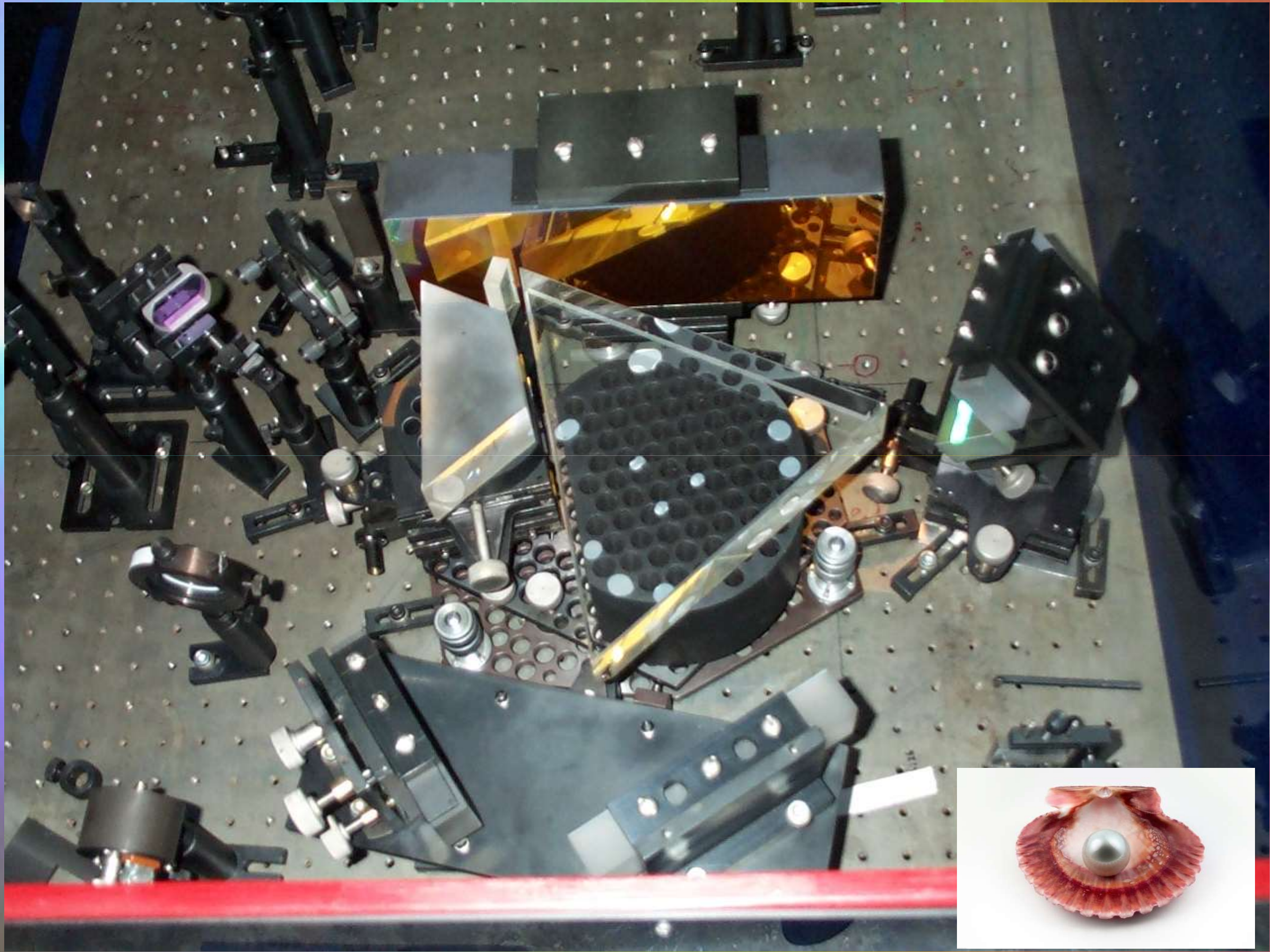
Spectrum of the output pulse



Schematic of light propagation through an eight-pass single-grating Offner stretcher. The circled numbers specify the sequence in which the pulse being chirped falls on the grating

PEARL – PEtawatt pARametric Laser

Hybrid prism-grating stretcher of PEARL laser system



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Nonlinear crystal KD*P for OPCPA

Laser Physics, Vol. 15, No. 9, 2005, pp. 1319–1333.

ADVANCED LASER SYSTEMS AND THEIR APPLICATIONS

Study of Broadband Optical Parametric Chirped Pulse Amplification in a DKDP Crystal Pumped by the Second Harmonic of a Nd:YLF Laser

V. V. Lozhkarev, G. I. Freidman, V. N. Ginzburg, E. A. Khazanov*, O. V. Palashov, A. M. Sergeev, and I. V. Yakovlev

Institute of Applied Physics, Russian Academy of Sciences, Nizhni Novgorod, 603950 Russia

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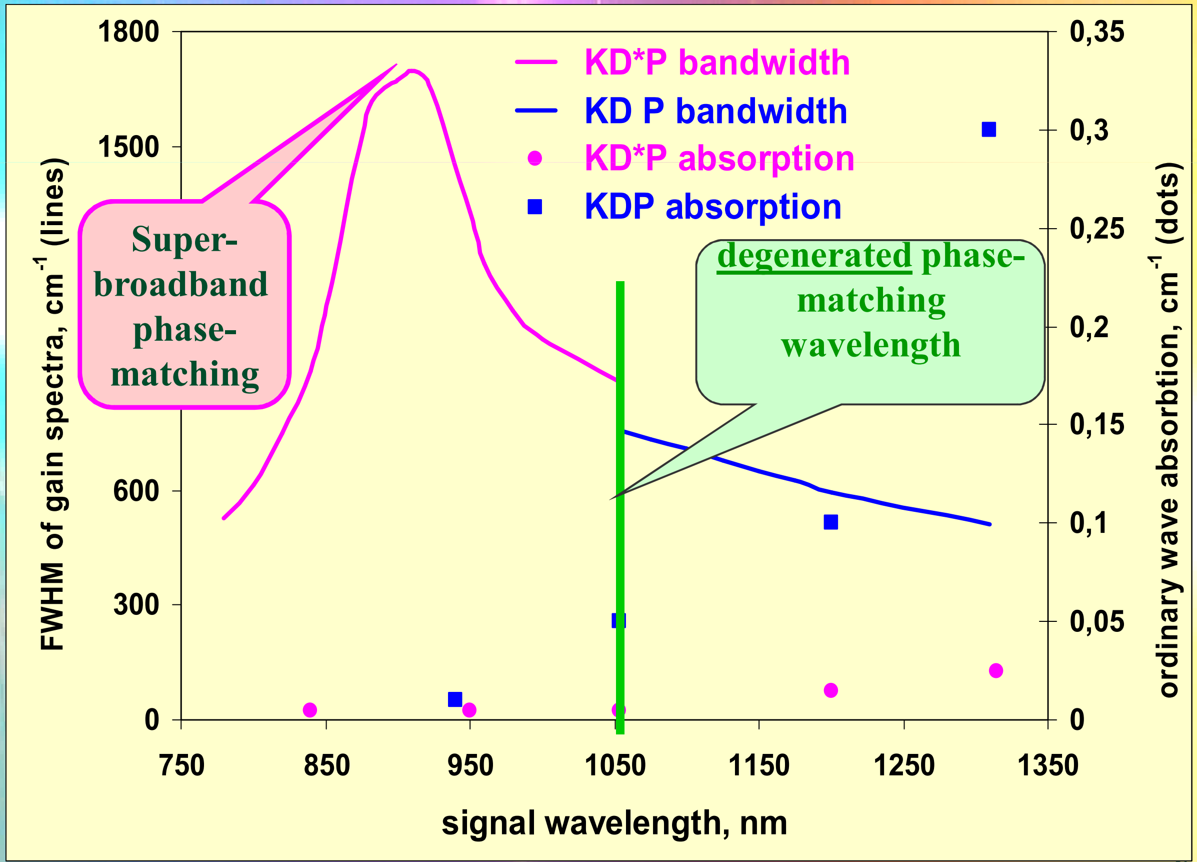
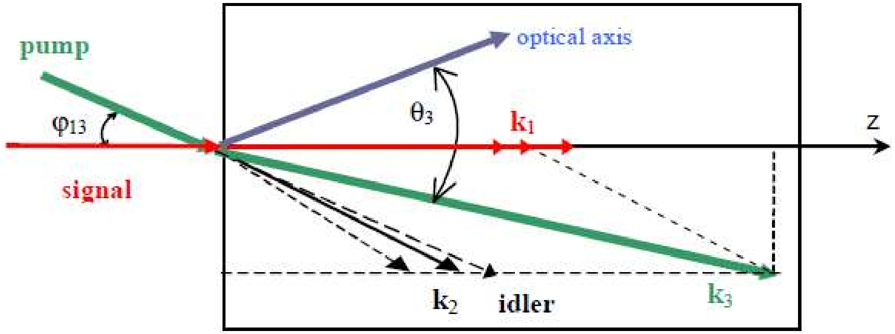
Received December 27, 2004

For the pump wavelength of 527 nm the optimal wavelength of the collimated signal radiation is 910 nm.

The wavelength of conjugated radiation is 1250 nm.

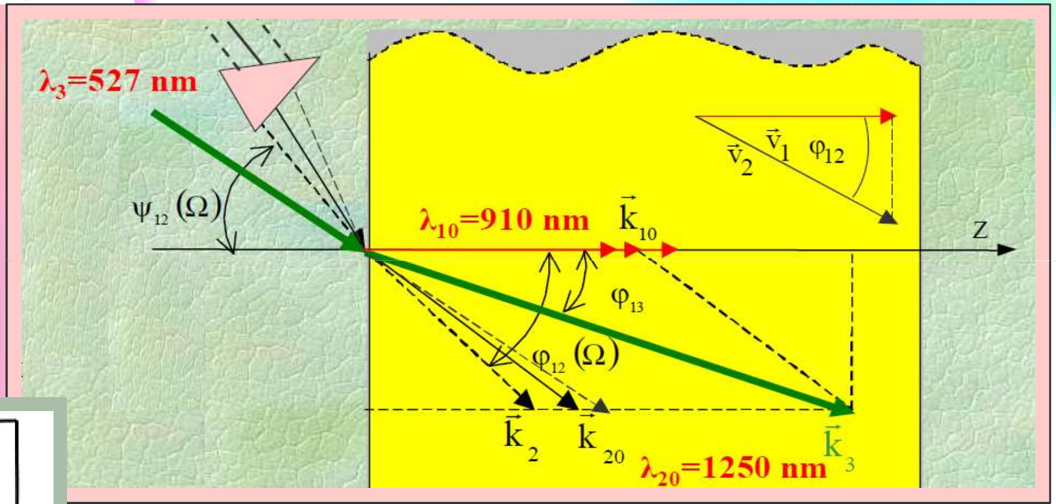


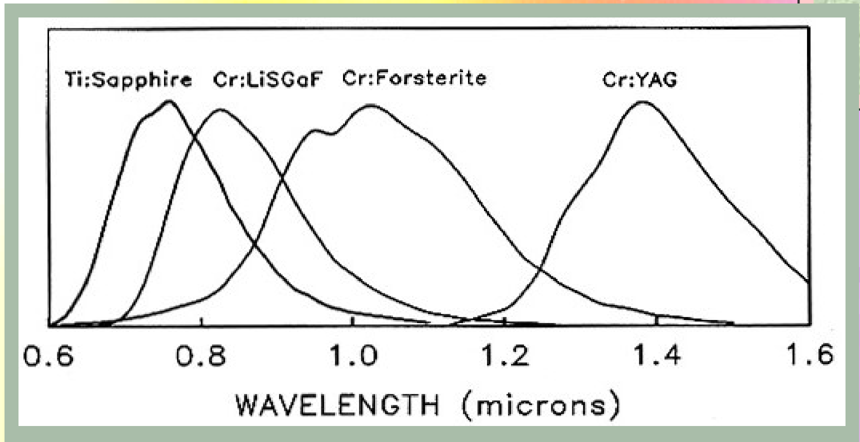
Choice of femtosecond master-oscillator



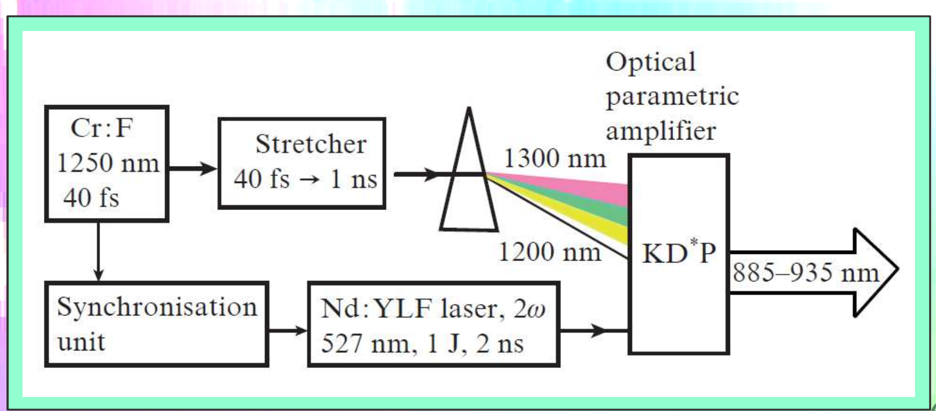
Two possible schematic diagram of non-collinear three-wave interaction in a nonlinear crystal at OPCPA of broadband signal radiation.

What is better: collimated signal radiation or an idle wave as a seed?





Luminescence spectra of the most widely used broadband materials

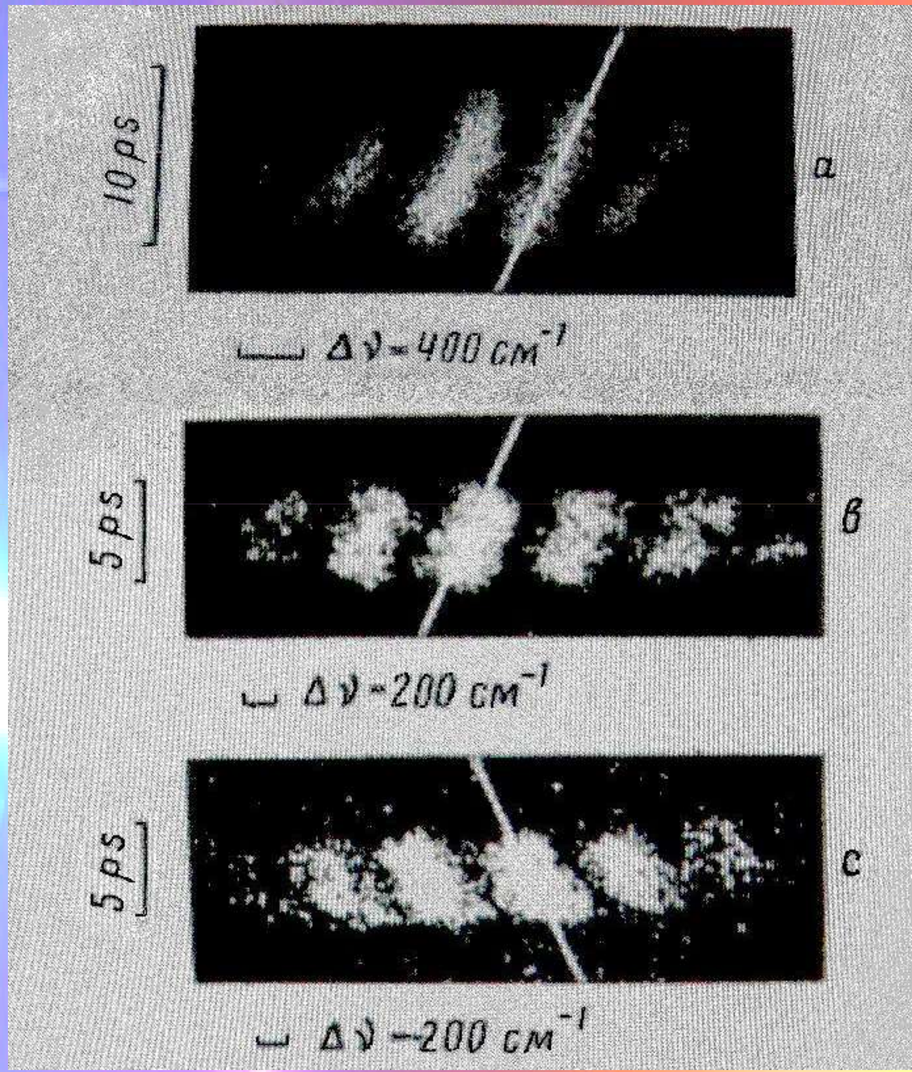


Chirp reversal

In three-wave interaction, the linear chirps of the idle and signal waves have the opposite sign.

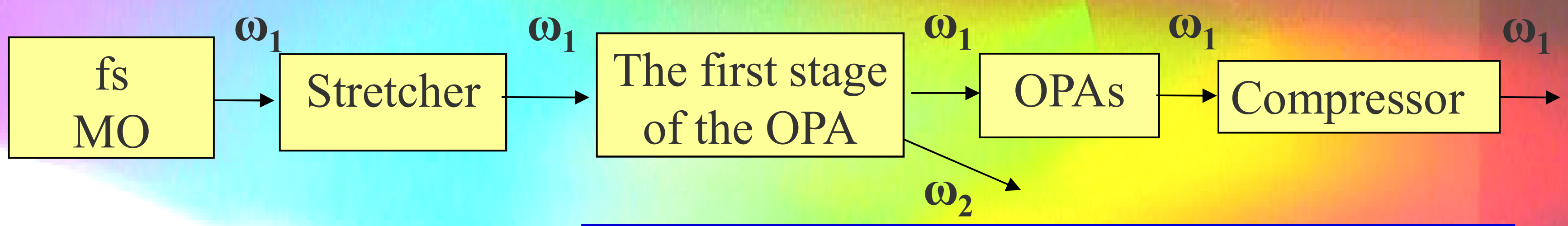
$$\Delta\Phi_1(\omega_{10}+\Omega) = -\ \Delta\Phi_2(\omega_{20}-\Omega)$$

R. Danelius, A. Piskarskas, V. Sirutkaitis, A. Stabinis, and A. Yankauskas, "Chirp reversal of picosecond light pulses in parametric amplification in quadratically nonlinear media," JETP Lett. 42, 122–124 (1985).



Phase matching condition of stretcher and compressor

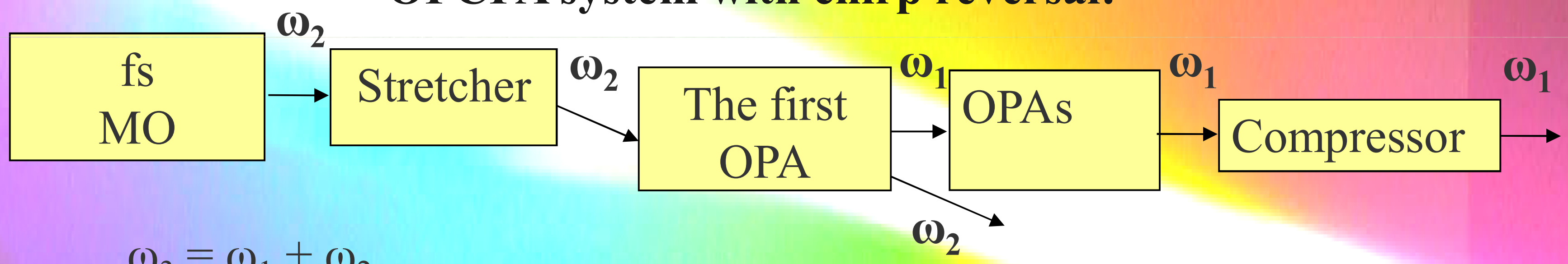
Traditional CPA and OPCPA systems:



We neglected the additional phase of the amplifier

$$\Delta\Phi_{str}^{(i)}(\omega_1) = -\,\Delta\Phi_{com}^{(i)}(\omega_1),\ \ i=2,3,\dots$$

OPCPA system with chirp reversal:



$$\omega_3 = \omega_1 + \omega_2$$

$$(\omega_{10} + \Omega_1) = \omega_3 - (\omega_{20} + \Omega_2)$$

$$\Omega_2 = -\,\Omega_1$$

$$\Phi_{sig}(\Omega) = -\,\Phi_{str}(-\Omega)+\Phi_{com}(\Omega)$$

The frequencies (wavelengths) of the stretched and compressed radiation are different!

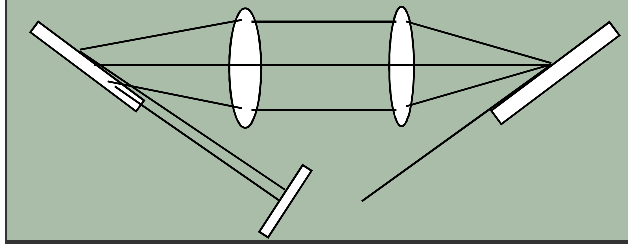
$\Phi^{(2)}{}_{str} = \Phi^{(2)}{}_{com}$, $\Phi^{(3)}{}_{str} = -\,\Phi^{(3)}{}_{com}$, $\Phi^{(4)}{}_{str} = \Phi^{(4)}{}_{com}$, etc.

$$\Delta\Phi_{str}^{(i)}(\omega_2) = (-1)^i\,\Delta\Phi_{com}^{(i)}(\omega_1),\ \ i=2,3,\dots$$

OPCPA

fs master oscillator

$\Phi \;=\; const$



$$\Delta\Phi = -\Phi'_c\Omega - \frac{1}{2}\Phi^{II}_c\Omega^2 - \frac{1}{3!}\Phi^{III}_c\Omega^3 - \frac{1}{4!}\Phi^{IV}_c\Omega^4 - \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$

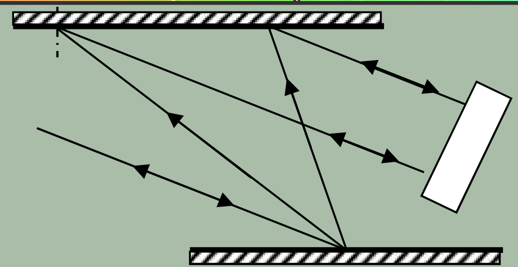
$$\Phi = -\Phi'_c\Omega - \frac{1}{2}\Phi^{II}_c\Omega^2 - \frac{1}{3!}\Phi^{III}_c\Omega^3 - \frac{1}{4!}\Phi^{IV}_c\Omega^4 - \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$

OPA

signal to signal

$$\Phi_{signal}(\omega_s+\Omega) = +\Phi_{\mathbf{signal}}(\omega_{\mathbf{s}} +\Omega)$$

$$\Phi = -\Phi'_c\Omega - \frac{1}{2}\Phi^{II}_c\Omega^2 - \frac{1}{3!}\Phi^{III}_c\Omega^3 - \frac{1}{4!}\Phi^{IV}_c\Omega^4 - \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$



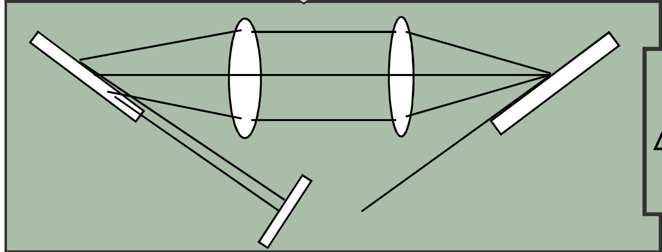
$$\Delta\Phi = \Phi'_c\Omega + \frac{1}{2}\Phi^{II}_c\Omega^2 + \frac{1}{3!}\Phi^{III}_c\Omega^3 + \frac{1}{4!}\Phi^{IV}_c\Omega^4 + \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$

$$\Phi = (\Phi'_c - \Phi'_c)\Omega + \frac{1}{2}(\Phi^{II}_c - \Phi^{II}_c)\Omega^2 + \frac{1}{3!}(\Phi^{III}_c - \Phi^{III}_c)\Omega^3 + \frac{1}{4!}(\Phi^{IV}_c - \Phi^{IV}_c)\Omega^4 + \frac{1}{5!}(\Phi^{V}_c - \Phi^{V}_c)\Omega^5 + ..$$

OPRCPA

fs master oscillator

$\Phi \quad = \quad const$



$$\Delta\Phi = -\Phi'_c\Omega - \frac{1}{2}\Phi^{II}_c\Omega^2 - \frac{1}{3!}\Phi^{III}_c\Omega^3 - \frac{1}{4!}\Phi^{IV}_c\Omega^4 - \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$

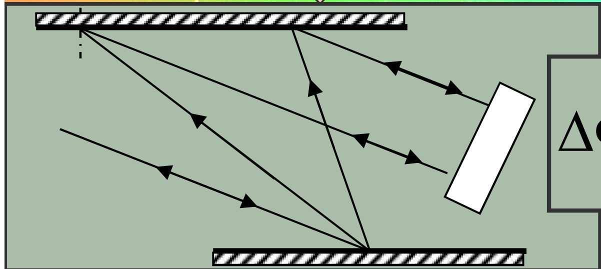
$$\Phi = -\Phi'_c\Omega - \frac{1}{2}\Phi^{II}_c\Omega^2 - \frac{1}{3!}\Phi^{III}_c\Omega^3 - \frac{1}{4!}\Phi^{IV}_c\Omega^4 - \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$

OPA

idler to signal

$$\Phi_{signal}(\omega_s + \Omega) = -\Phi_{\mathbf{idler}}(\omega_{\mathbf{i}} - \Omega)$$

$$\Phi = -\Phi'_c\Omega + \frac{1}{2}\Phi^{II}_c\Omega^2 - \frac{1}{3!}\Phi^{III}_c\Omega^3 + \frac{1}{4!}\Phi^{IV}_c\Omega^4 - \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$



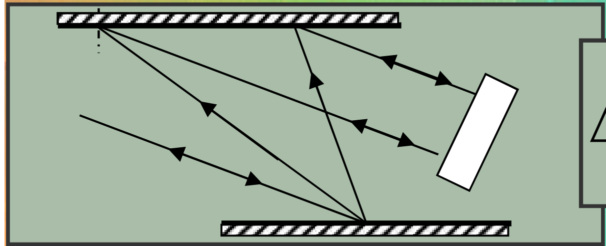
$$\Delta\Phi = \Phi'_c\Omega + \frac{1}{2}\Phi^{II}_c\Omega^2 + \frac{1}{3!}\Phi^{III}_c\Omega^3 + \frac{1}{4!}\Phi^{IV}_c\Omega^4 + \frac{1}{5!}\Phi^{V}_c\Omega^5 + \dots$$

$$\Phi = (\Phi'_c - \Phi'_c)\Omega + \frac{1}{2}(\Phi^{II}_c + \Phi^{II}_c)\Omega^2 + \frac{1}{3!}(\Phi^{III}_c - \Phi^{III}_c)\Omega^3 + \frac{1}{4!}(\Phi^{IV}_c + \Phi^{IV}_c)\Omega^4 + \frac{1}{5!}(\Phi^{V}_c - \Phi^{V}_c)\Omega^5 + \dots$$

fs master oscillator

OPRCPA

$$\Phi = const$$



$$\Delta\Phi = +\Phi'_c\Omega + \frac{1}{2}\Phi_c^{II}\Omega^2 + \frac{1}{3!}\Phi_c^{III}\Omega^3 + \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \ldots$$

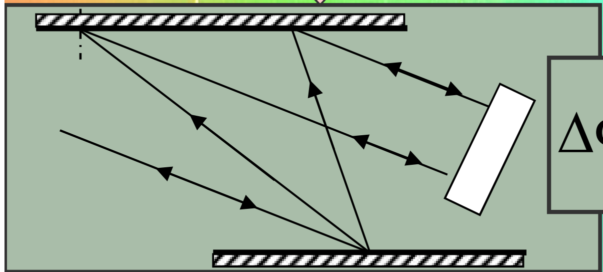
$$\Phi = +\Phi'_c\Omega + \frac{1}{2}\Phi_c^{II}\Omega^2 + \frac{1}{3!}\Phi_c^{III}\Omega^3 + \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \ldots$$

OPA

idler to signal

$$\Phi_{signal}(\omega_s + \Omega) = -\Phi_{idler}(\omega_i - \Omega)$$

$$\Phi = +\Phi'_c\Omega - \frac{1}{2}\Phi_c^{II}\Omega^2 + \frac{1}{3!}\Phi_c^{III}\Omega^3 - \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \ldots$$



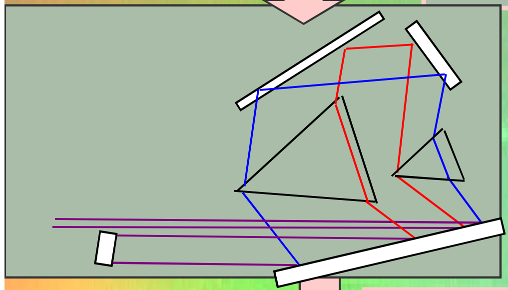
$$\Delta\Phi = \Phi'_c\Omega + \frac{1}{2}\Phi_c^{II}\Omega^2 + \frac{1}{3!}\Phi_c^{III}\Omega^3 + \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \ldots$$

$$\Phi = (\Phi'_c + \Phi'_c)\Omega + \frac{1}{2}(\Phi_c^{II} - \Phi_c^{II})\Omega^2 + \frac{1}{3!}(\Phi_c^{III} + \Phi_c^{III})\Omega^3 + \frac{1}{4!}(\Phi_c^{IV} - \Phi_c^{IV})\Omega^4 + \frac{1}{5!}(\Phi_c^{V} + \Phi_c^{V})\Omega^5 + \ldots$$

OPRCPA

fs master oscillator

$\Phi = const$



$$\Delta\Phi = +\Phi'_c\Omega + \frac{1}{2}\Phi_c^{II}\Omega^2 - \frac{1}{3!}\Phi_c^{III}\Omega^3 + \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \dots$$

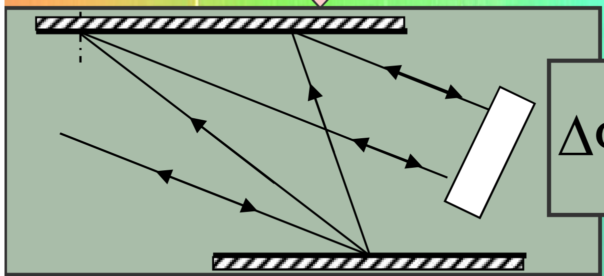
$$\Phi = +\Phi'_c\Omega + \frac{1}{2}\Phi_c^{II}\Omega^2 - \frac{1}{3!}\Phi_c^{III}\Omega^3 + \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \dots$$

OPA

idler to signal

$$\Phi_{signal}(\omega_s+\Omega) = -\Phi_{idler}(\omega_i-\Omega)$$

$$\Phi = +\Phi'_c\Omega - \frac{1}{2}\Phi_c^{II}\Omega^2 - \frac{1}{3!}\Phi_c^{III}\Omega^3 - \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \dots$$

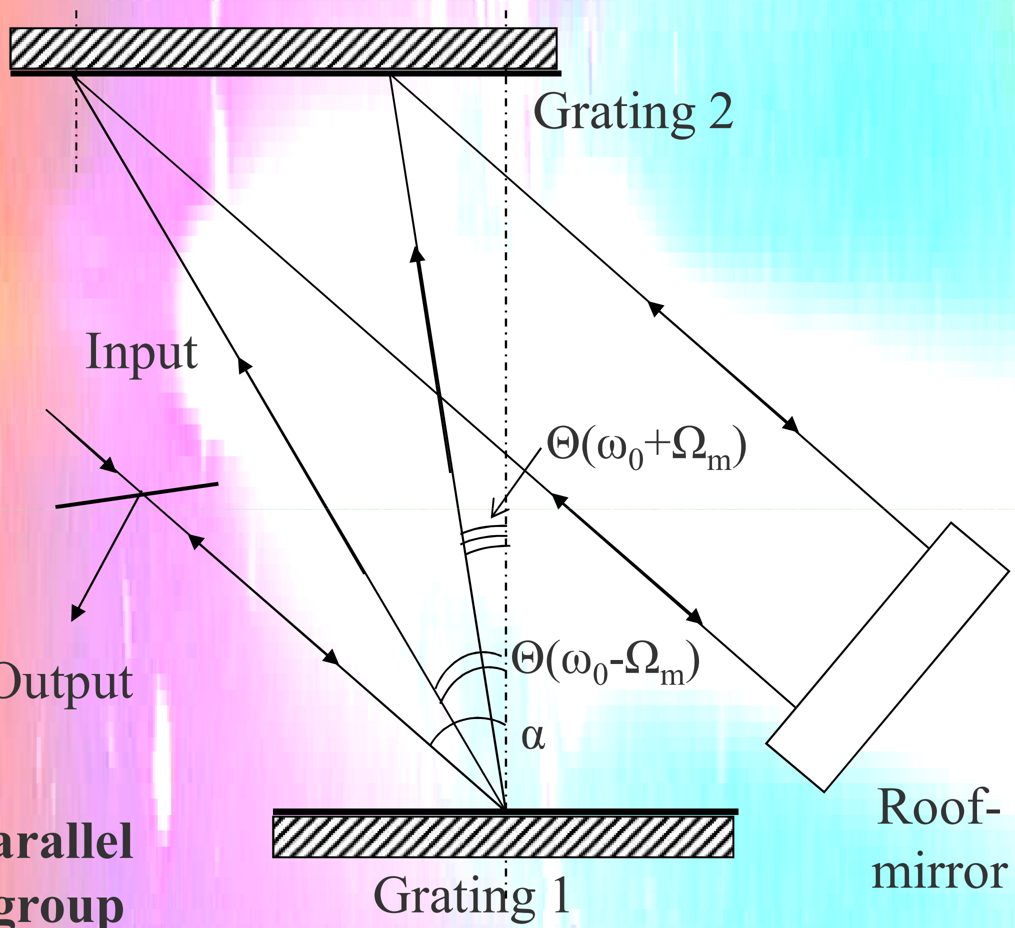


$$\Delta\Phi = \Phi'_c\Omega + \frac{1}{2}\Phi_c^{II}\Omega^2 + \frac{1}{3!}\Phi_c^{III}\Omega^3 + \frac{1}{4!}\Phi_c^{IV}\Omega^4 + \frac{1}{5!}\Phi_c^{V}\Omega^5 + \dots$$

$$\Phi = (\Phi'_c + \Phi'_c)\Omega + \frac{1}{2}(\Phi_c^{II} - \Phi_c^{II})\Omega^2 + \frac{1}{3!}(\Phi_c^{III} - \Phi_c^{III})\Omega^3 + \frac{1}{4!}(\Phi_c^{IV} - \Phi_c^{IV})\Omega^4 + \frac{1}{5!}(\Phi_c^{V} + \Phi_c^{V})\Omega^5 + \dots$$

The classical Treacy compressor

Edmond B. Treacy, "Optical Pulse Compression With Diffraction Gratings", IEEE J. Quant. Electron. QE-5, 454-458 (1969).



Spectral phase of compressor:

$$\Phi_{com}(\omega)=\omega/c\ L_0\cos(\theta)$$

$$\left(\frac{d^2\Phi}{d\omega^2}\right)_{\omega 0} = \frac{-L_0\lambda_0^3}{2\pi c^2 d^2 \cos(\theta_0)^3}$$

The system based on two parallel gratings provides negative group velocity dispersion (GVD)

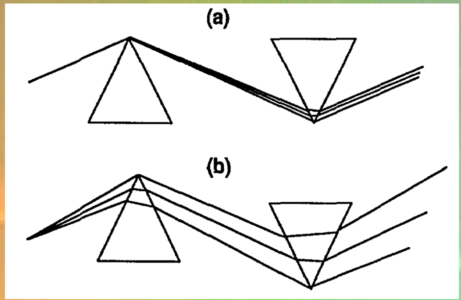
$$\sin\alpha + \sin\Theta = m\,\lambda / d$$

454 IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. QE-5, NO. 9, SEPTEMBER 1969

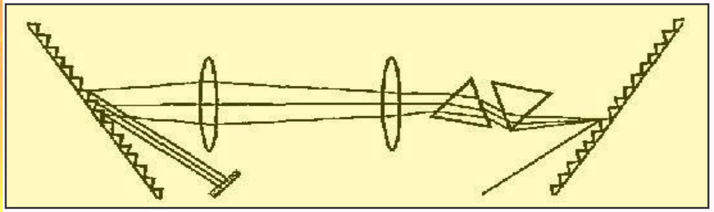
Optical Pulse Compression With Diffraction Gratings

EDMOND B. TREACY, MEMBER, IEEE

Hybrid grating-prism stretcher

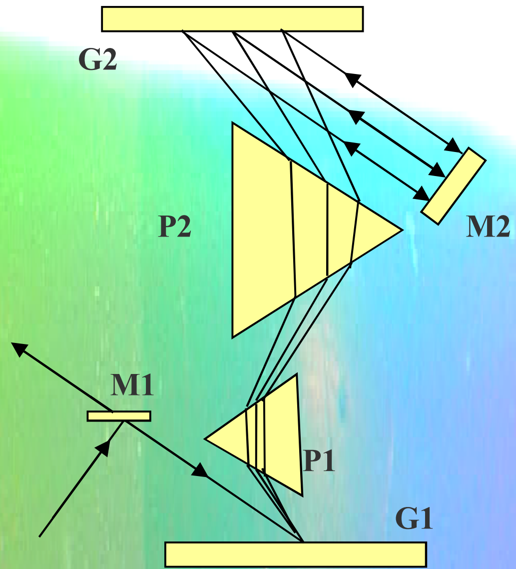


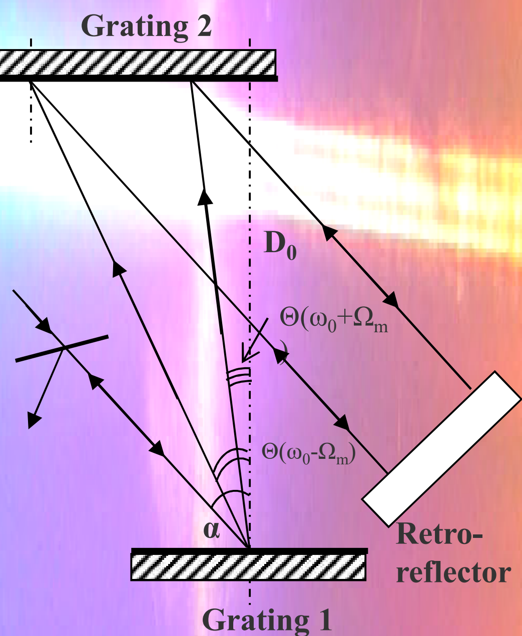
A prism pair, located between the diffraction gratings in a divergent beam, can make a more significant contribution to the cubic phase of the system than in the case of a collimated beam falling on the prisms.



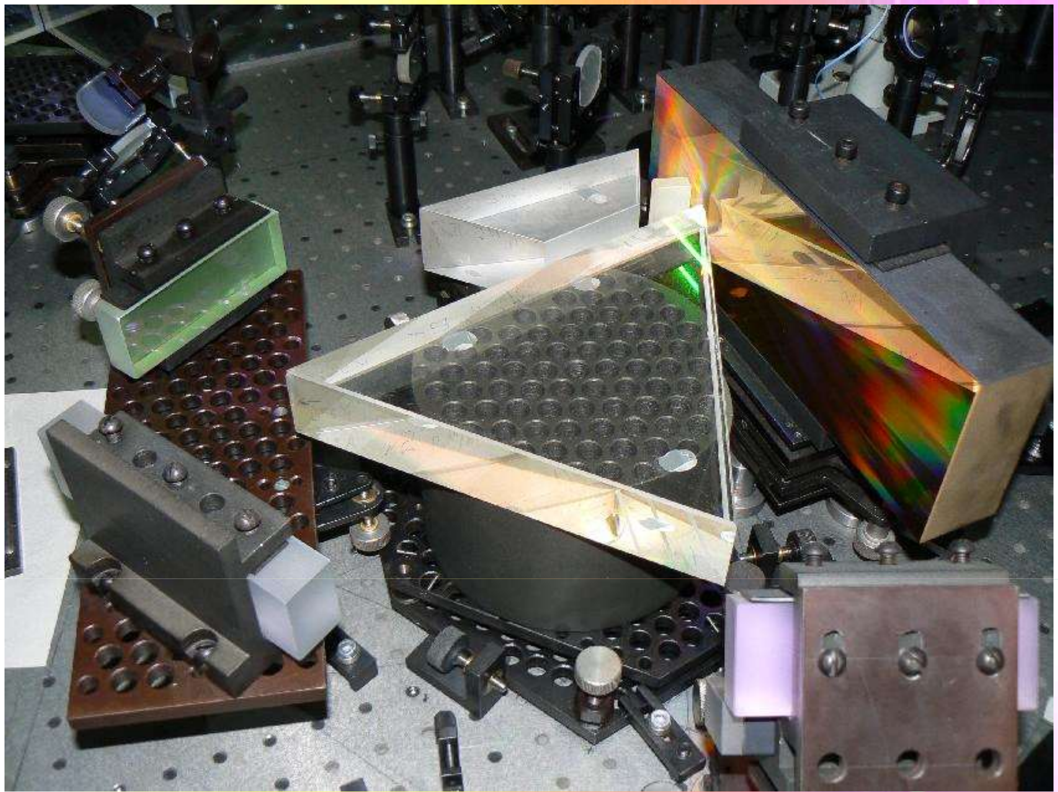
S.Kane, J.Squier, J.V.Rudd, and G.Mourou, "Hybrid Grating-Prism Stretcher-Compressor System with Cubic Phase and Wavelength Tunability and Decreased Alignment Sensitivity", Opt.Lett., 19, 1876-1878 (1994).

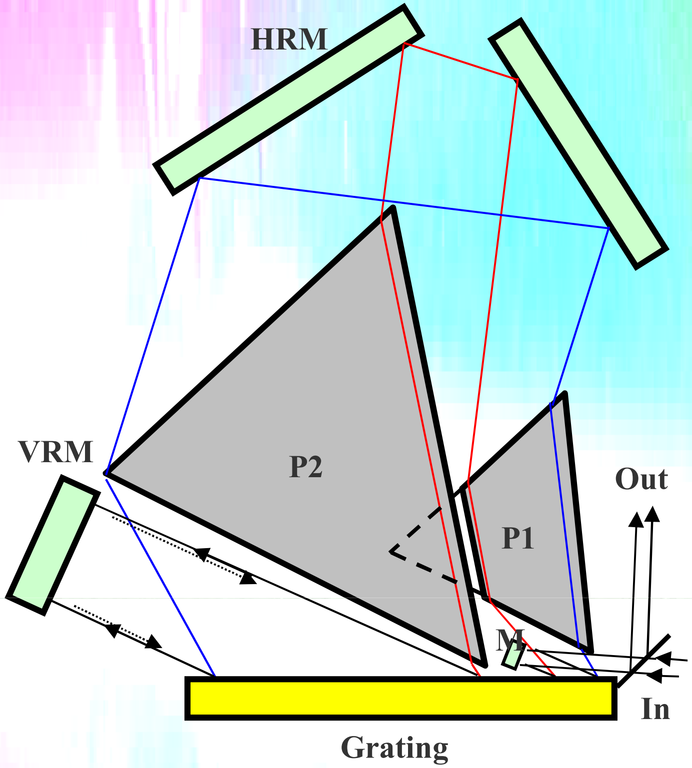
Prism/grating aberration-free stretcher design for PEARL system





Prism/grating aberration-free stretcher design for PEARL system





A single-grating scheme of the stretcher was developed.

Calculations showed that a stretcher with a pair of intragrating prisms allows to accurately compensate the residual dispersion up to the 4-th order inclusive for the OPRCPA system.

A central wavelength - 1250 nm
The bandwidth - 1000 cm^{-1}
Transmission coefficient - 50%

G.I. Freidman and I.V. Yakovlev, *"New stretcher scheme for a parametric amplifier of chirped pulses with frequency conversion"*, Quantum Electron. 37(2), 147-148, 2007.

Grisms

Optics Communications 357 (2015) 71–77

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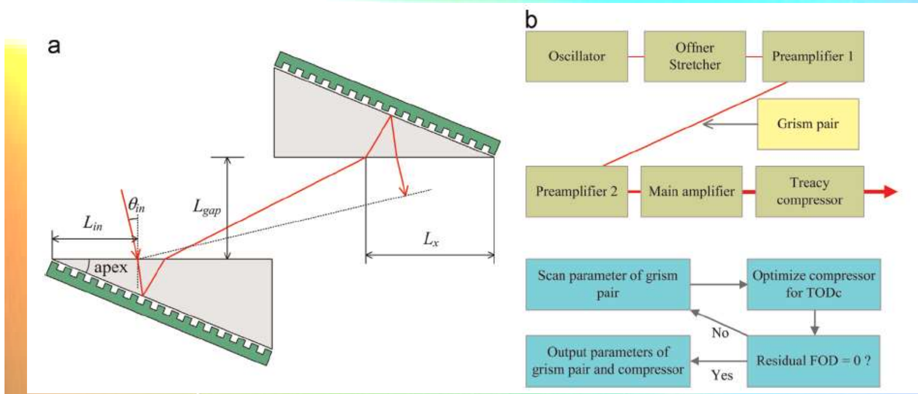
journal homepage: www.elsevier.com/locate/optcom

Fourth-order dispersion compensation for ultra-high power femtosecond lasers

Zhaoyang Li[a,b,c], Cheng Wang[a], Shuai Li[a], Yi Xu[a], Lei Chen[b], Yaping Dai[c], Yuxin Leng[a,*]

[a] State Key Laboratory of High Field Laser Physics, Shanghai institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
[b] School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China
[c] Graduate School, China Academy of Engineering Physics, Mianyang 621900, China



Optics Communications 411 (2018) 88–92

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Hybrid grating–prism dispersion eraser

Cheng Wang[a,*], Shuai Li[a,b], Yanqi Liu[a], Xingyan Liu[a,c], Yuxin Leng[a,*], Ruxin Li[a]

[a] State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
[b] University of Chinese Academy of Sciences, Chinese Academy of Sciences, Beijing, 100049, China
[c] School of Physical Science and Technology, ShanghaiTech University, Shanghai 200031, China

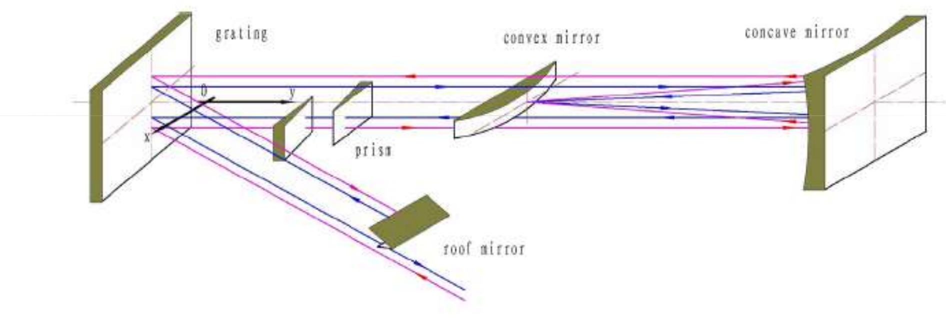


Fig. 1. Schematic of a hybrid grating–prism dispersion eraser.

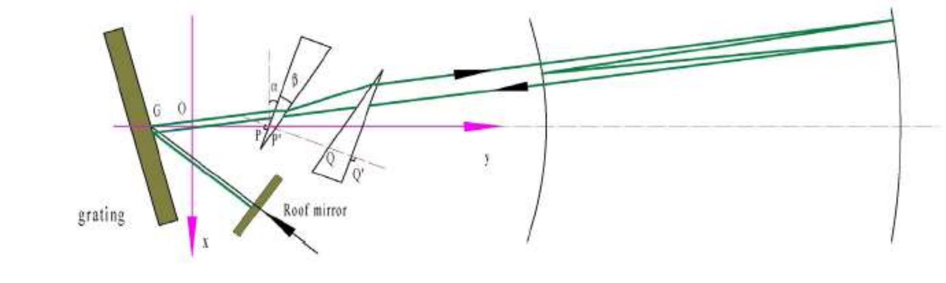
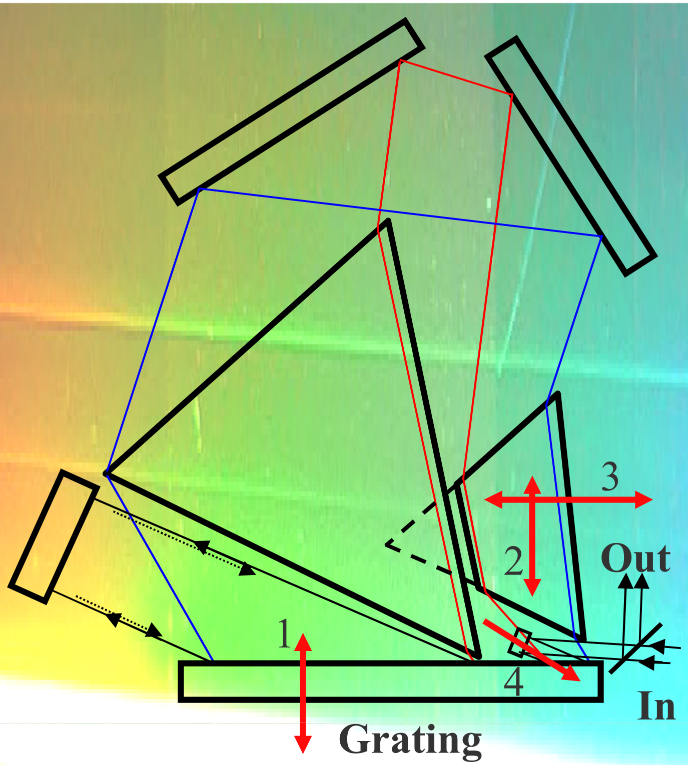
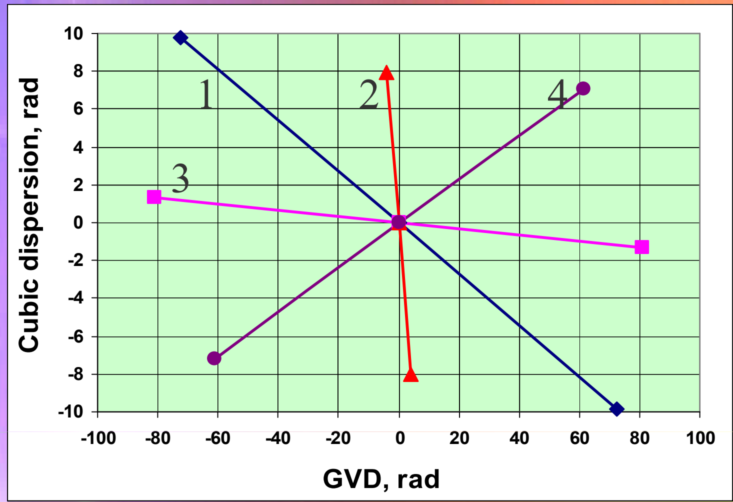


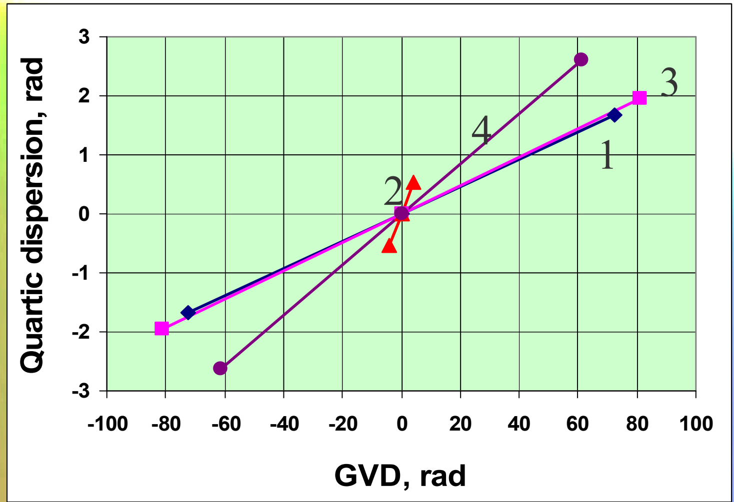
Fig. 2. 2-dimension numerical model.

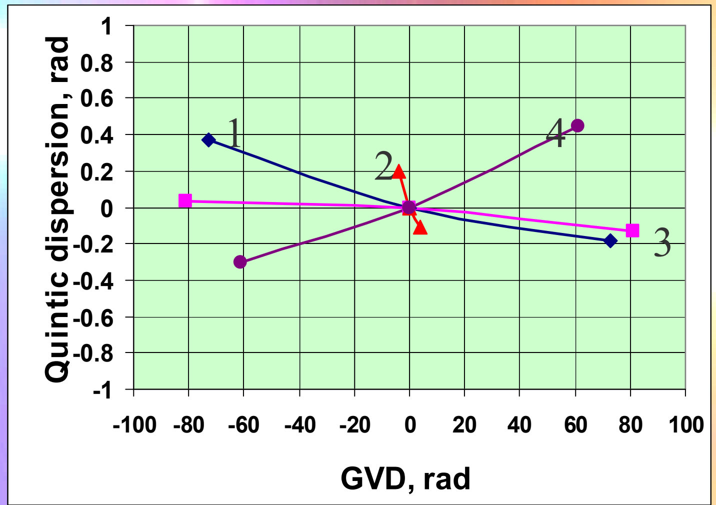
Residual dispersion compensation

By changing the position of the grating and prism, as well as the angle of incidence of the beam, it is possible to control the dispersions of the stretcher



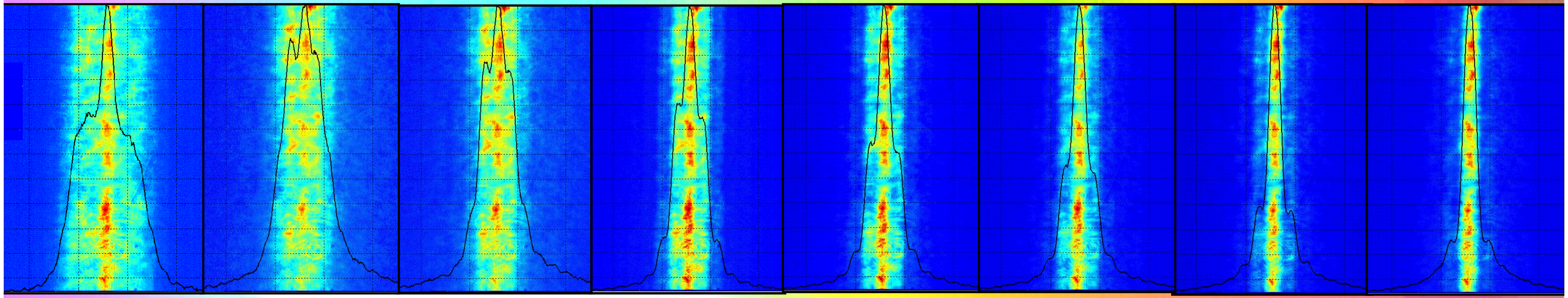




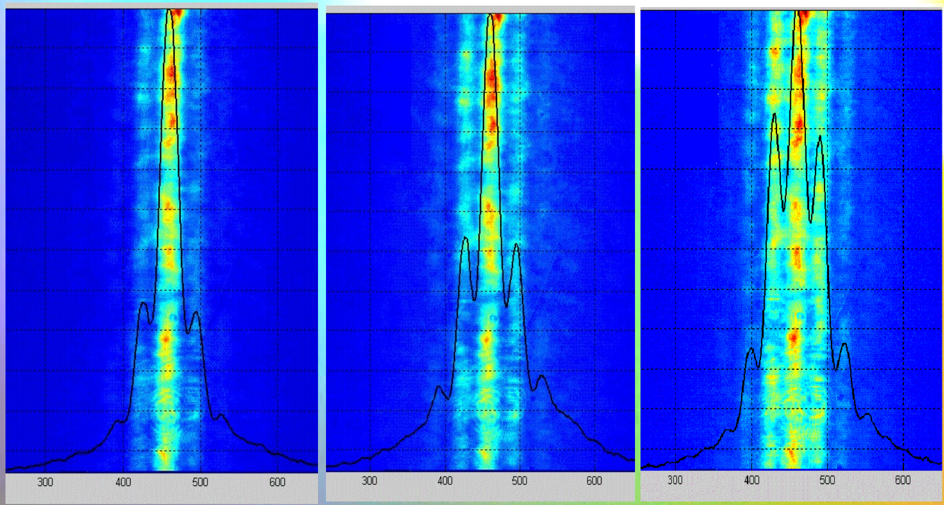


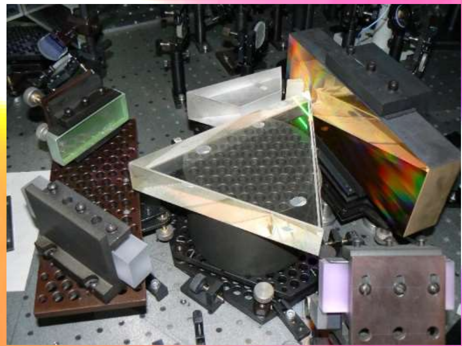
1 - grating shift, 2&3 – small prism shift, 4 - change the angle of incidence

Single-shot ACF series obtained when changing compressor base by means of the grating moving in the direction normal to the operating surface



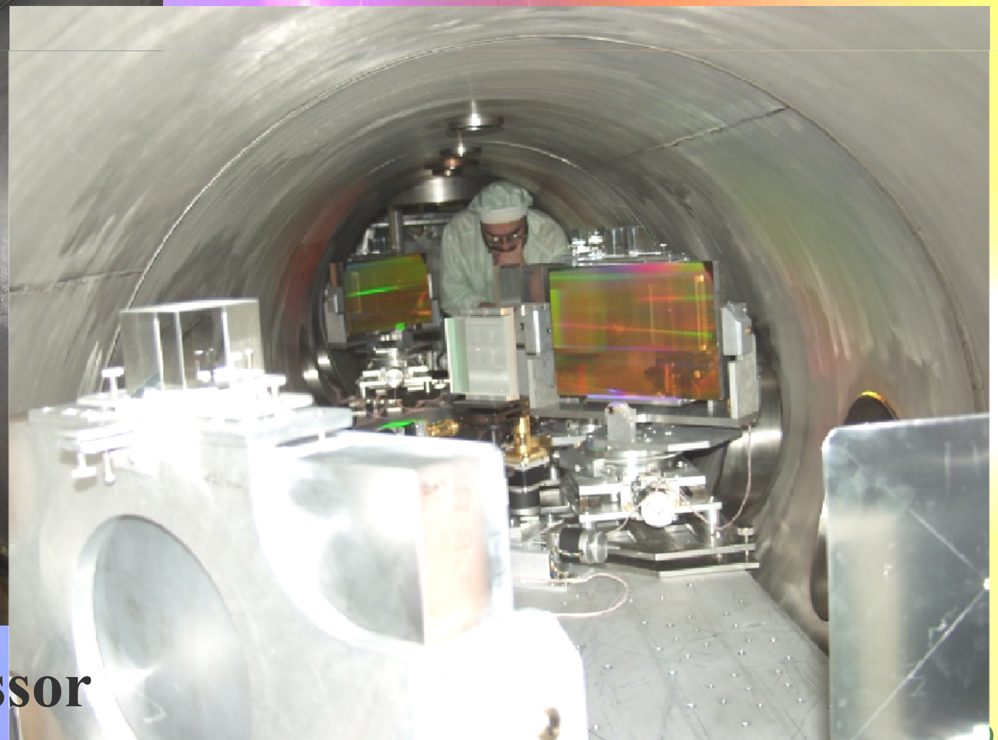
The effect of third order dispersion on the ACF form





Some task: get 2 pulses from a laser system with significantly different durations: 60 ps and 60 fs.
To get 60 ps pulses at the compressor output, it is require to detune the compressor base (the distance between each pair of gratings) by 16 cm.
Such a large shift is not possible due to the technical limitations of the mechanical translators used.

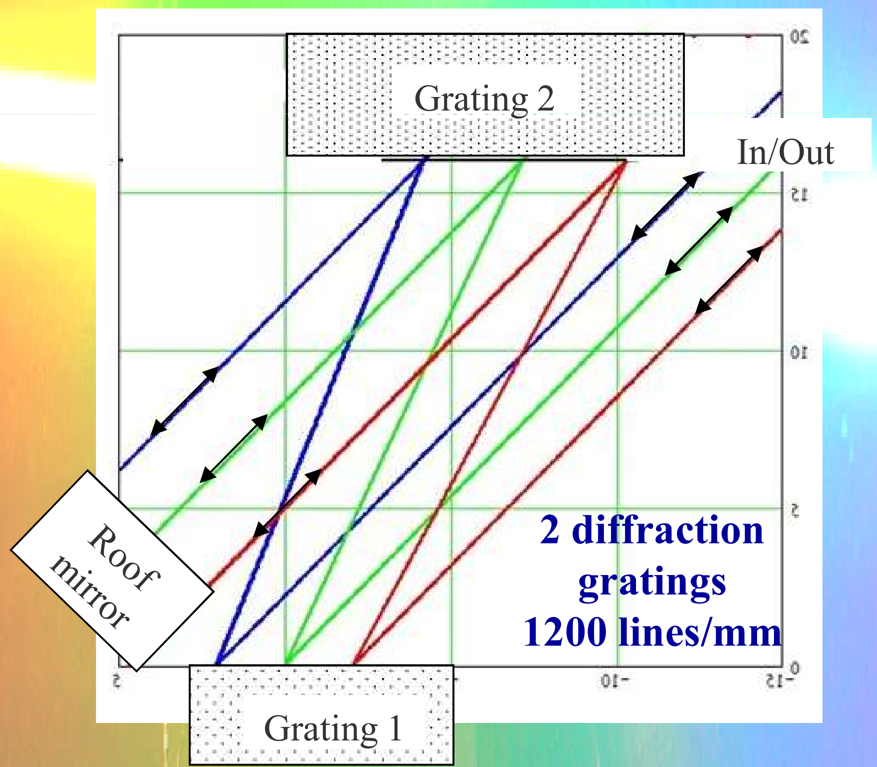
4 diffraction gratings
420x220 mm, 1200 lines/mm
inside compressor



PEARL laser system compressor

An alternative way to obtain picosecond pulses is to shift the stretcher grating. The calculations showed that the shift of the horizontal roof mirror only to 3 cm from the grating and moving a small prism on 1 cm needs to provide the duration of the output pulses of the compressor 60 ps. In this case, the pulse will be "under-compressed", i.e., to obtain a femtosecond pulse, an additional system on diffraction gratings is required.

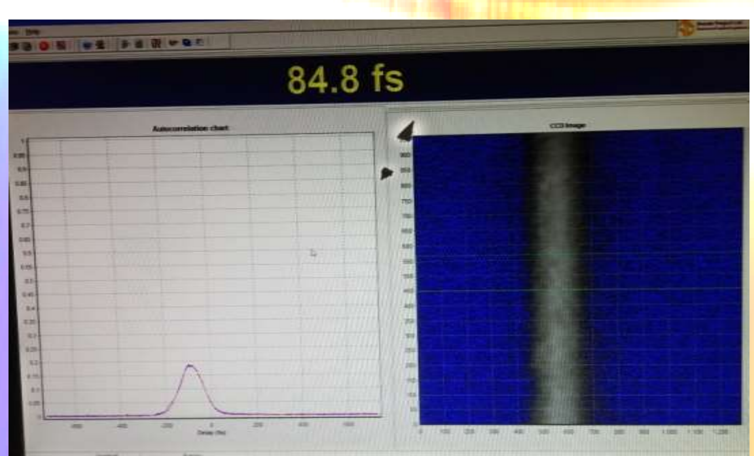
Such an additional compressor was created on two diffraction gratings with a groovs density of 1200 l./mm and a base of 16 cm.



The scheme of small additional compressor

The beam with a diameter of 3 cm was cut off from the main laser beam by a mirror and directed to an additional compressor.

The resulting autocorrelation function.




Thank you